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ARMSTRONG LABORATORY

TRAINING REQUIREMENTS UTILITY MEASUREMENT

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This report has been reviewed and is approved for publication.

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Opportunities for in-flight training for air combat pilots are becoming increasingly constrained. Limitations include safety, cost, airspace, and security. Combat engagement simulations allow human warfighters and their simulated weapon systems to engage other warfighters on a virtual battlefield. Two systems for multiplayer, air combat simulation were evaluated. One system was based on super-minicomputers by United States Air Force F-15 pilots and air weapons controllers for acceptability and training effectiveness.

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PREFACE

This effort was conducted as part of Project 2743, Multiship Research and Development (Multirad). The objective of Multirad is to provide qualitative and quantitative data that will enhance the technology base and for acquiring advanced training system capabilities. This technology base will help the Air Force define and document requirements for future training systems, identify potential training benefits, and determine simulation complexity.

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Crane, P. (1994). Air Combat Training Systems for the Journeyman Pilot. In, Proceedings: Applied Behavioral Sciences Symposium, Colorado Springs, CO: United States Air Force Academy.

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TRAINING REQUIREMENTS UTILITY EVALUATION

INTRODUCTION

Today's air combat pilot faces a difficult mission. Situation awareness must be maintained in spite of incomplete and often inconsistent data. Enemy aircraft must be found and destroyed. Communications and electronic jamming must be overcome. Enemy weapons must be defeated using countermeasures and maneuvers. In addition, the pilot must successfully execute these individual tasks as a member of an extended team of warfighters.

Training for this mission during peacetime is expensive and difficult. Most combat mission training occurs in unit-level continuation training programs. These programs provide the apprenticeship environment in which the pilots develop their skills through on-the-job training and practice. The unit's continuation training program gives pilots the opportunity to learn how to employ their weapon systems effectively and to practice as part of a combat team.

While the cornerstone of a unit's continuation training program is in-flight training, several factors combine to limit in-flight training opportunities for many combat skills (United States Air Force Scientific Advisory Board, 1992). These factors include security restrictions, safety of flight considerations, resources, and range space. In addition, resource and range space constraints also limit the opportunities for collective training as part of larger force units (Defense Science Board, 1976; 1988). These training limitations suggest the need for additional training in many key mission areas. Operational pilots, training managers, and air weapon controllers have repeatedly stated their desire for additional training in many combat mission activities (Gray, Edwards, & Andrews, 1993; Houck, Thomas, & Bell, 1991). Table 1 shows eight of the combat mission activities for which pilots frequently request additional training opportunities.

Table 1. Mission Activities for Which Additional Training is Desired

Multi-bogey, four or more
Defense against all-aspect threats
Reaction to surface-to-air missiles
Dissimilar air combat tactics
Four-ship tactics
Reaction to air interceptors
Employment of electronic countermeasures and electronic counter-countermeasures
Chaff and flare employment

McDONNELL AIRCRAFT SIMULATIONS

Combat engagement simulations allow human warfighters and their simulated weapon systems to engage other warfighters on a virtual battlefield. These simulations are becoming increasingly realistic because of the continuing advances in computer and communication technologies. Perhaps the best known example of such combat engagement simulations is the simulator networking (SIMNET) program. This program was sponsored by the Advanced Research Projects Agency (ARPA) in cooperation with the Army and showed the successful use of combat engagement simulation for the collective training of combat units (Alluisi, 1991).

Based on the potential of programs like SIMNET, the Armstrong Laboratory was directed in the late 1980s to evaluate multiship simulation for air combat training. The laboratory responded to this direction with a combined behavioral and engineering program conducted with the cooperation of the Air Combat Command. First, we identified potential weapon systems and mission activities that could benefit

from multiship combat simulation. Next, before starting a long and potentially expensive development effort, we conducted an operational training utility evaluation using existing simulation facilities. The purpose of this evaluation phase was to learn if ground-based simulation was acceptable for combat mission training. To reduce costs and obtain information as quickly as possible, a two-versus-many air combat simulation was used at McDonnell Aircraft Company (MCAIR) in St. Louis, MO.

MCAIR System Components

The simulation system used at MCAIR was designed to support engineering development. Its design and equipment represent the full-mission simulator facilities developed by aircraft manufacturers in the late 1980s. Figure 1 shows the principal components of this system. Each F-15 cockpit was located in a 40-ft diameter dome. The visual world was created by a combination of CompuScene IV image generators and video target projectors. Enemy surface-to-air and electronic jammers were provided through a computer-based threat system. Enemy aircraft consisted of both piloted and computer-controlled adversaries. The manned enemy aircraft were flown using low fidelity, manned interactive control stations. Human participants on both sides were supported by air weapons controllers.

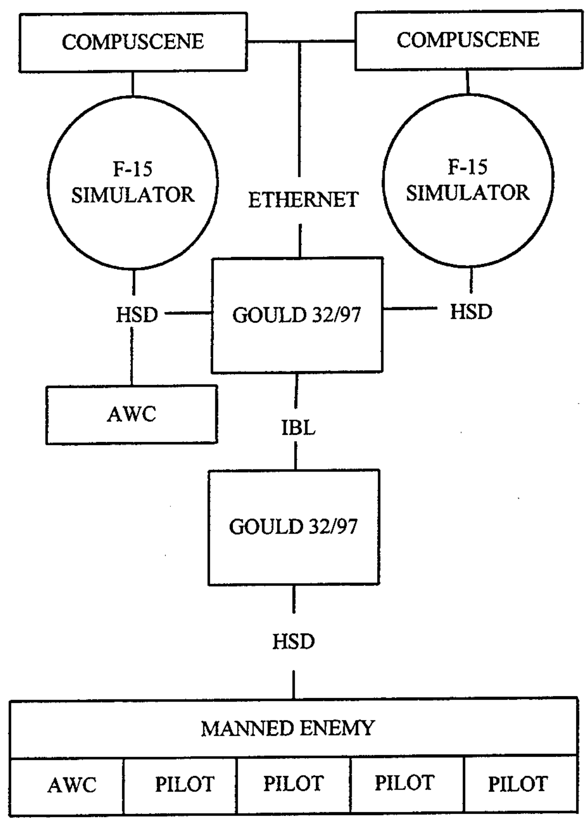

Figure 1. McDonnell Aircraft Simulation Components.

Two Gould 32/97 super minicomputers connected by an Inter-Bus Link served as the host computers for this simulation. The simulators and other peripheral devices were connected to these computers by High Speed Devices and Ethernet. A more detailed description of this simulation is available in McDonnell, Broeder, and Cutak (1989).

Training Utility Evaluation

Fourteen weeks of air combat simulations were flown. Each week consisted of four days of simulated combat missions. An average of twelve pilots and six air weapons controllers took part in each training week. The participants flew as a formed team for the entire week. Each formed team consisted of a flight lead and wingman from the same fighter squadron and an air weapons controller. The team flew at least one simulator sortie each day. Each simulator sortie lasted about one hour and involved a specific air combat mission (e.g., fighter sweep, point defense, force escort).

The simulator training was designed using a building block approach in which mission difficulty was manipulated for each team based on their performance. Mission difficulty was controlled by varying threat capabilities, weather, electronic and communication jamming, and threat tactics. Each team typically flew four separate combat engagements in the hour sortie. A more detailed description of this evaluation is available in Houck, Thomas, and Bell (1991).

Pilots and air weapon controllers received feedback about their mission performance through a variety of sources. Within each simulator all systems and displays responded appropriately. Engagement results produced real-time outcomes that included kill-removal and battle damage. The visual system allowed the pilot to see missiles, tracers, other aircraft, and explosions. All communications between the pilots and between the pilots and the air weapons controller were recorded. Each F-15 pilot's radar warning receiver and radar display were recorded for each engagement. This information was combined with a plan-view display of the engagement to support the team's post-mission debrief. In addition, an instructor pilot monitored their cockpit instruments and voice communications from the test director's station.

The responses of both pilots and air weapons controllers to the air combat simulations were extremely positive. Table 2 shows those combat activities pilots felt were better trained in this multiship simulation than in their unit training program. These include the combat activities that are difficult to train in-flight because of resource limitations, security restrictions, and safety constraints. The pilots also identified several combat activities for which their unit training program was superior to this multiship air combat simulation. These activities, listed in Table 3, require high visual resolution. Even though the MCAIR domes provided state-of-the-art target and laser projection systems, they still could not provide the pilots with enough resolution to enable them to see the visual cues they rely on in their in-flight training.

Conclusions

The results of this operational training utility evaluation show the potential value of using simulators to help train pilots and air weapons controllers in air combat skills. Both Air Force pilots and air weapons controllers reported that multiship air combat simulation provided better training for many combat activities than their current unit training program.

DISTRIBUTED INTERACTIVE SIMULATION IMPLEMENTATION

Although the training utility evaluation at McDonnell Aircraft Company showed that multiship simulation could complement continuation training for many critical combat activities, the Air Force could not afford to buy and maintain a similar system. Therefore, more affordable alternatives must be developed and evaluated if multiship simulations are to become an integral part of continuation training.

The Multiship Research and Development (Multirad) program at Armstrong Laboratory, Aircrew Training Research Division (AL/HRA) was undertaken to create a system that would provide multiship air combat simulation using lower cost, distributed simulation. One of the goals of the Multirad program was to develop a simulation testbed using a SIMNET-type approach that would support training effectiveness

Table 2. F-15 Mission Activities for Which Multiship Simulator Training was Rated Significantly Higher than Unit Training

Multi-bogey, four or more
Reaction to surface-to-air missiles
Dissimilar air combat tactics
Employment of electronic countermeasures and electronic counter-countermeasures
Defense against all-aspect threats
Escort tactics
All-weather employment
Communications jamming
Low altitude tactics
Threat warning assessment

Table 3. F-15 Mission Activities for Which Multiship Simulator Training was Rated Significantly Lower than Unit Training

Visual lookout
Tactical formation
Visual identification
Mutual support

research. Once the simulators were integrated into the Multirad distributed simulation network, a series of training exercises known as the Training Requirements Utility Evaluation (TRUE) was conducted. The purpose of the TRUE, which replicated many elements of the MCAIR air combat simulations, was to find out if distributed simulation provided an acceptable simulation of two-versus-many air combat.

Multirad System Components

The Multirad system consists of several independent systems connected via network interface units (NIUs) which convert each device's unique codes into a common communication protocol. The components used in the TRUE were: two F-15 cockpits, computer image generation and displays for the F-15s, two opposing forces cockpits, an air weapons controller station, a computer-generated threat system, an exercise control and video recording station, and a separate video debriefing station (see Fig. 2).

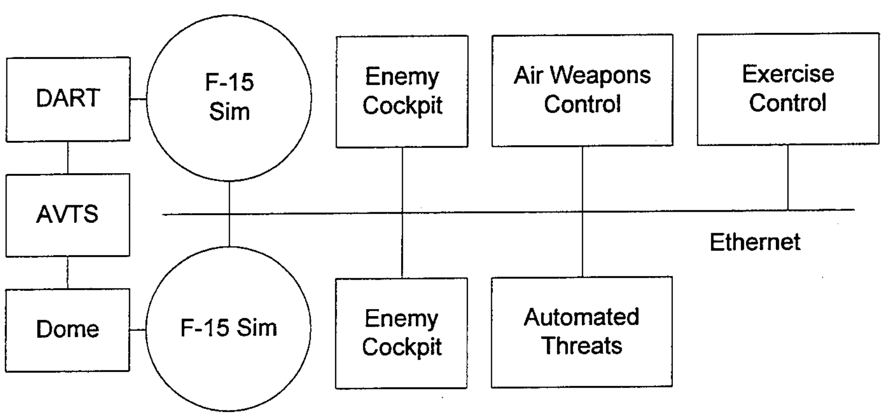

Figure 2. Multiship Research and Development (Multirad) System Network.

F-15 Cockpits

The two F-15C cockpits used were McDonnell Douglas Reconfigurable Cockpits (MDRCs). The MDRC incorporates high fidelity stick and throttle grips with a color CRT/touchscreen depiction of the front panel (see Fig. 3). The MDRC uses commercial, off-the-shelf, VME-based, microprocessors to perform all internal functions. Inside its single VME chassis, the MDRC has four Motorola 68030 single board computers, one Motorola quad-processor (88100) computer board, two computer image generator board sets, a sound board, and several digital-to-analog and analog-to-digital converters. The two image generators are used to provide the cockpit instruments and the head-up display (HUD). The sound board provides weapons cues and aircraft audio such as engine sounds and g-limit warnings.

The MDRC has a high fidelity F-15 software suite that is derived directly from the McDonnell Douglas engineering simulators in St. Louis. The software includes an F-15 aerodynamics package, a full assortment of air-to-air weapons, a complete radar package, a radar warning receiver (RWR), a HUD, electronic countermeasures (ECM), and electronic counter-countermeasures capabilities (ECCM). The MDRC provides high fidelity simulation only for air combat functions; there are no rudder pedals or provisions for takeoff, landing, refueling, or emergency procedures.

F-15 Visuals

Computer Image Generation - Imagery was provided by the General Electric Advanced Visual Technology System (AVTS) which was the engineering prototype for the CompuScene 4. AVTS provides 8,000 faces distributed among ten channels at 60 Hz.

Displays - One MDRC was installed in the McDonnell Douglas full field-of-view dome. This system consists of a 24-ft diameter dome with 360 deg horizontal by 190 deg vertical coverage (Reno, 1989). The display system incorporates six background projectors with a resolution of 4.3 arc-min/pixel and a 40 deg, head-tracked area of interest (AOI) (see Fig. 4).

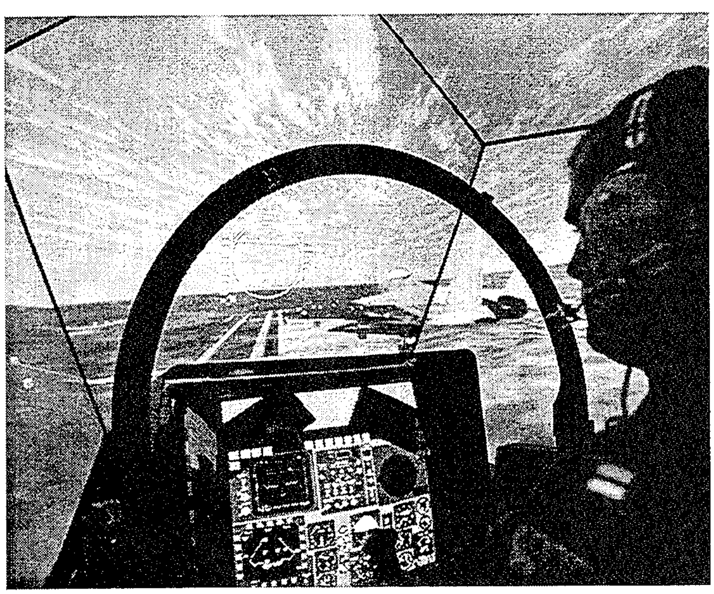

Figure 3. McDonnell Douglas Reconfigurable Cockpit (MDRC) Installed in the Display for Advanced Research and Training (DART).

Resolution in the AOI was 2.4 arc-min/pixel. Only the AOI and the three forward channels were used during the TRUE resulting in an 210 deg horizontal by 100 deg background field of view. The AOI could be slewed throughout the dome. The other MDRC was installed in the Armstrong Laboratory Display for Advanced Research and Training (DART). The DART is a dome-like display system consisting of eight segments of a dodecahedron which surround the cockpit (Thomas, Reining, & Kelly, 1991). Each segment is a rear-projection screen approximately 1m from the pilot's head (Fig. 3). During the TRUE, imagery was projected onto only six of the screens at a time as controlled by a head tracker. The DART's field of view during the TRUE was 300 deg horizontal by 200 deg vertical with resolution of 4.75 arc-min/pixel. Unlike the dome pilot, the DART pilot could not see to the rear of the aircraft.

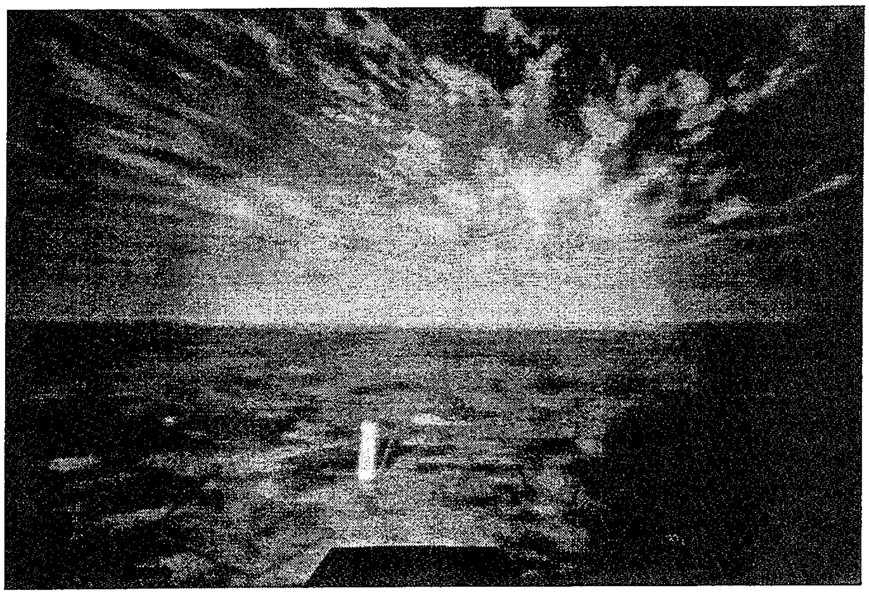

Figure 4. Interior of the Full Field-of-View Dome (Cockpit has been removed).

Opposing Forces Cockpits

Two Armstrong Laboratory Combat Engagement Trainers (CETs) were integrated into the network as opposing airborne interceptors (Fig. 5). CETs are limited-function F-16 trainers equipped with air-to-air radar, AIM-9 missiles, and radar warning receivers (Boyle & Edwards, 1992). For the TRUE, the F-16 aerodynamics simulation was replaced with aerodynamic and engine characteristics of an Su-27 (Flanker) interceptor.

Air Weapons Controller Station

The Simulated Command and Control Environment Networked Training System (SCCENTS) was developed by the Logistics Research Division of Armstrong Laboratory to provide the Air Force with a low-cost command and control workstation for research, development, and training (Fig. 6). The system was designed to be integrated to networks such as SIMNET or Distributed Interactive Simulation (DIS). The SCCENTS has two display modes - an Airborne Warning and Control System (AWACS) or the 407L Ground Control Intercept (GCI) display. The AWACS display was used for TRUE research because it provided more physical information about the battle to the controllers. The SCCENTS also has a geographic database developed from Defense Mapping Agency data.

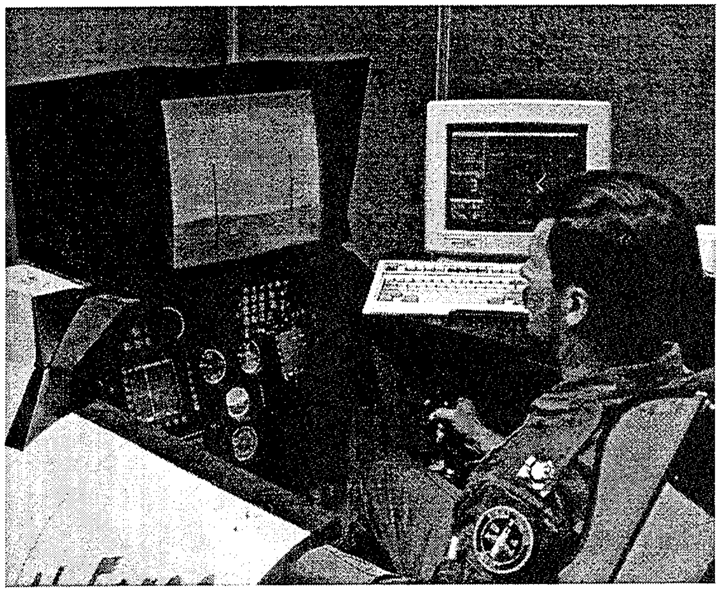

Figure 5. Limited Function Combat Engagement Trainer (CET)

Computer-Generated Threats

The F-15 and opposing forces cockpits, visual image generators, displays, and the controller station were existing systems which were adapted for network operation. The automated threat engagement system (ATES) was developed especially for the Multirad effort (Rogers, 1992). The ATES simulates ground and air threats plus friendly aircraft. Ground threats include: headquarters functions with early warning radar, directed and autonomous surface-to-air missile (SAM) batteries (SA-4, SA-6, and SA-8) with their radars, and ZSU-23 anti-aircraft artillery (AAA). ATES air threats used in the

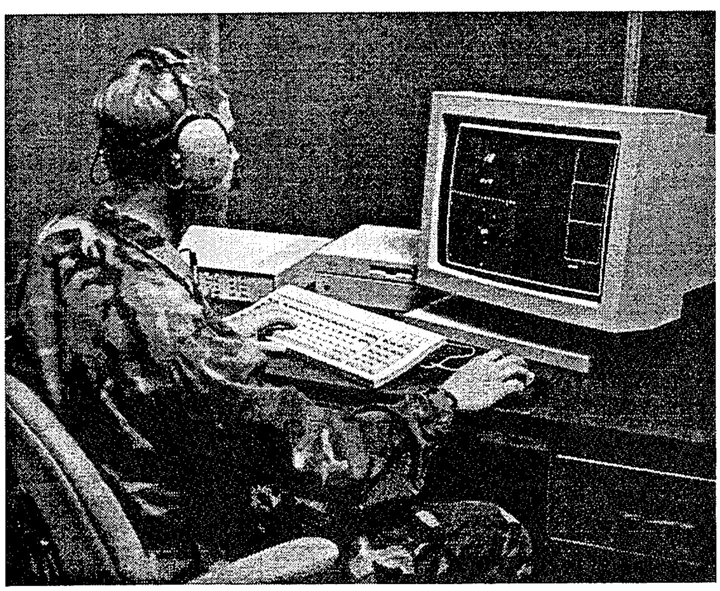

Figure 6. Simulated Command and Control Environment Networked Training System (SCCENTS) Used as the Air Weapons Controller Station.

TRUE were Su-27 interceptors armed with radar and infrared guided missiles and MiG-27 (Flogger) attack fighters equipped with radar jammers. ATES also supplied four F-16 strike fighters used during offensive counterair missions. While the ATES hardware was specifically developed for Multirad, the threat models and integrating software are, "a blend of several programs from various government agencies and a commercial vendor," (Rogers, 1992, p. 303).

Exercise Control

Multiship simulation exercises were directed from a central console which contained systems to set up, initiate, observe, videotape, and terminate sorties. Initial conditions and actions of automated opposing forces were preprogrammed in the ATES. Initial conditions for all manned players are programmed in the exercise control station. Monitors at the control station displayed: (a) an overhead view of the engagement, (b) each F-15's front panel including radar, radar warning, and armament control displays, and (c) one channel of out-the-window video (the AOI for the dome and the forward channel for the DART) (Fig. 7). The test director had intercom communication with each player station. Incorporated into the exercise control station was a computer-controlled, videotaping system which recorded the two F-15 front panels and the overhead view plus all radio communication. Computer control allowed synchronized start, stop, and playback of the three videotapes.

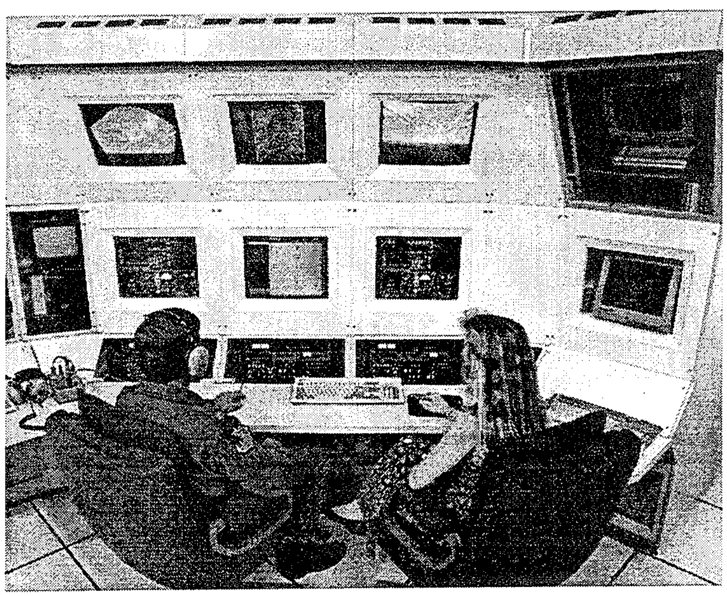

Figure 7. Multirad Exercise Command and Control Station.

Debriefing station

After each simulator session, the two F-15 pilots and the air weapons controller would take the videotapes to an independent debriefing room which contained three computer-controlled tape players and monitors (Fig. 8). After brief instruction, participants were able to review their engagements and could stop, rewind, and replay segments of particular interest. Since the debriefing system was independent of the simulators, a second team could fly while the first was debriefing.

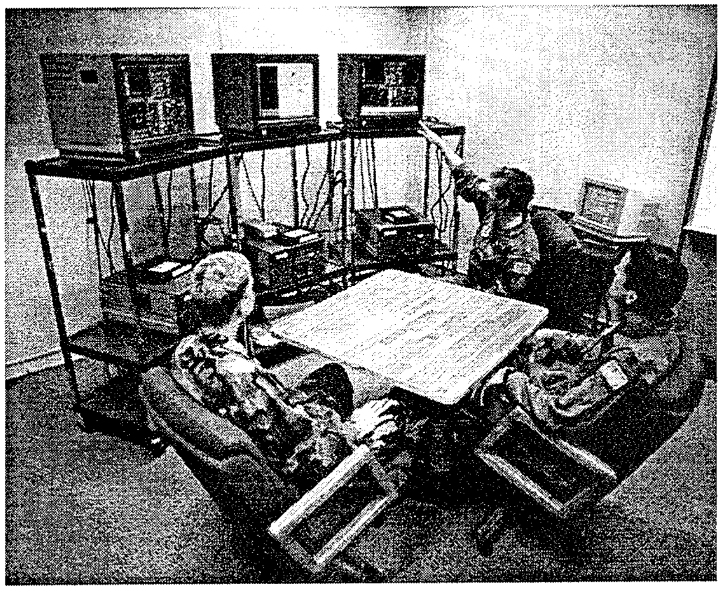

Figure 8. Multirad Video Debriefing System.

System Development and Integration

Network Interface Units

The Network Interface Unit provides a method of communicating between the host simulator and the Multirad network (SIMNET). The NIU and host communicate with one another according to a predefined language which is described in the system's interface control document (ICD). The NIU uses ethernet as the physical medium to communicate both with the host computer and SIMNET although other mediums such as Fiber Distributed Data Interface (FDDI) and reflective memory are available for use. The NIU's primary functions include coordinate system conversion, remote vehicle approximation (RVA), data filtering, and conversion of units of measure. RVA algorithms were used to reduce the amount of data on the Multirad network. The algorithms use linear interpolation to determine a vehicle's new position. All moving entities on the network had RVA models of 10 m long, 20 m wide, 1 m high, and 3 deg rotational. If a model's delta between the actual position and RVA position exceeded 10% for any of these dimensions, an appearance packet was sent to all other vehicles on the network.

Armstrong Laboratory developed one NIU for each of its networked simulation systems. The NIU's hardware consists of two Motorola 68030 single board computers with transition modules, an enhanced ethernet interface board from CMC Corporation, a SIMVAD digital voice processing board, a SIMVAD voice communications adapter with a headset, a twelve-slot VME chassis, and a removable disk drive assembly. One computer board processed simulation data between the SIMNET network and the simulation host while the other board processed digital voice data between the host and the network. The CMC ethernet processor board was chosen for communications between the NIU and SIMNET because it was faster than the MVME712 transition module interface. The CMC boards also contained firmware to monitor ethernet statistics such as collisions and bad packets.

Communications Protocol and Extensions

SIMNET was developed by the Army and ARPA for tanks and slow moving air vehicles. Armstrong Laboratory implemented a subset of the SIMNET Protocol Data Units (PDUs) specific to air combat operations. Initially, the activate request and response, deactivate request and response, vehicle

appearance, fire, and impact PDUs were implemented and tested. After all systems were able to communicate with each other and observe each other in the synthetic battlefield, the protocols were extended to include freeze, radar, and emitter PDUs. The MDRCs provided the most fidelity and were chosen to provide the testbed for implementing the protocol extensions. The MDRCs were first tested one on one, then integrated to the other devices on the network.

All SIMNET PDUs were modified to add a timestamp field. Additionally, fifteen extra result types were added to the impact PDU to enhance scoring capabilities. Originally, the SIMNET protocol only had four results for scoring: miss, ground impact, vehicle impact, and proximity impact. A freeze PDU was also implemented to allow the exercise control station to stop (freeze), and continue any mission.

The radar and emitter PDUs were designed to pass all the information needed about a specific radar or emitter over the network to other vehicles. The radar PDU includes radar system, radar mode, radar ID, sweep, power, and a list of illuminated targets. The emitter PDU includes the number of emitters, emitter class, mode, power, frequency, and sweep. Air-to-air Tactical Aid to Navigation (TACAN), Identification Friend or Foe (IFF), jammer, and radio emitters were specifically implemented on the network. One issue that had to be addressed was the classified nature of the radars and emitters of the MDRCs. Rather than send classified data over the network, all players had classified information about all other players on the net. In this way, PDUs were implemented such that individual packets were not classified but aggregates of packets may be classified.

Each system's level of computing ability was different. Initially, the MDRCs originally could only handle 8 threat vehicles, 8 missiles, and 8 ECM bodies. Upgrading the MDRCs to Motorola 88100 processors increased capability to support 15 threats, 8 network missiles, 8 internal missiles, 8 network ECM bodies, 8 internal ECM bodies, and 8 SAM/AAA sites. The CETs on the other hand could only handle 6 network vehicles. A priority routine was used to monitor the closest threats. Similar limitations existed in the visual systems where priority schemes were also implemented.

While integrating the MDRC to the network, a single vehicle update message was designed to transfer simulation information about all entities on the network. This single vehicle update message contained position, velocity, and state information including radars and emitters. However, ECM and missile entities do not need to pass information such as radars, emitters, and throttle position. A second, streamlined, vehicle appearance message was created for ECM and missiles to reduce the amount of traffic between the host and NIU.

Problems Encountered

Many unexpected problems arose during the integration of the systems for the TRUE. For example, the CETs and ATES were accepting any impact message containing their vehicle ID as a kill without looking at the result. Under certain circumstances, the MDRCs would kill vehicles when the gun trigger was depressed--even though the vehicle was 80 miles away. Ghost vehicles were also created on the network due to improper memory management. Still another memory management problem allowed vehicles to attain attributes of vehicles that were previously in that portion of memory. A CET might fly a jamming mission in one sortie; in the next sortie, whichever vehicle occupied the same memory space had the jammer flag set.

During development for TRUE, networked vehicles jittered in the visual systems. Several reasons for jitter were identified. One portion of the jitter occurred when a vehicle exceeded the RVA dimensions. Jitter was also caused by the different frequency rates of the devices on an asynchronous network. Still another cause for jitter was simulator or NIU overloading. When a device could not send and receive packets at its predefined update rate, it would take large jumps in the visual systems. Finally, coordinate conversions and precision were found to be contributors to jitter. In the early stages of TRUE development, some vehicles were making large jumps in the visuals. The coordinate transformation

algorithms in the NIUs were found to be incorrect. All systems were analyzed and modified to reduce the possibility of overloading. The scenarios were also analyzed to ensure devices did not overload due to network traffic. Additionally, the coordinate transformations were corrected. The resulting jitter was deemed acceptable to the program because it was minor. A smoothing algorithm could be used to further reduce the jitter but was not implemented due to system loading.

Test and Evaluation

TRUE was conducted as a series of air combat training exercises similar to the exercises conducted at McDonnell Aircraft Company. Three or four teams of lead and wing F-15 pilots plus an air weapons controller participated in four, week-long exercises. During each of these weeks, teams flew seven, one-hour simulator sessions. During each session, teams flew three or four setups of either a defensive (DCA) or offensive (OCA) counter-air mission. On DCA missions, the team defended their home airbase against an attack from two MiG-27 (Flogger) fighter-bombers escorted by four Su-27 (Flanker) fighters (two manned and two computer-generated). On OCA missions, the F-15s escorted a flight of four computer-generated F-16s attacking the air base which was defended by six Su-27 fighters, four computer-generated and two manned. Each DCA or OCA setup was initiated with the aircraft at 20,000 ft separated by 80 nmi. Computer-generated enemy force tactics were preprogrammed and the manned players followed a script during the early part of each engagement. There were six variations of enemy tactics for the OCA mission and seven for the DCA mission. In addition, the manned players were free to deviate from the script as circumstances demanded and the computer-generated aircraft were programmed to defend themselves when attacked. Figures 9 and 10 illustrate two variations of the DCA and OCA missions. F-15 pilots and controllers were not shown the enemy force plans nor were they informed about which variation would be seen on any setup. Variations were selected at random with the provision that no variation was repeated within a given simulator session.

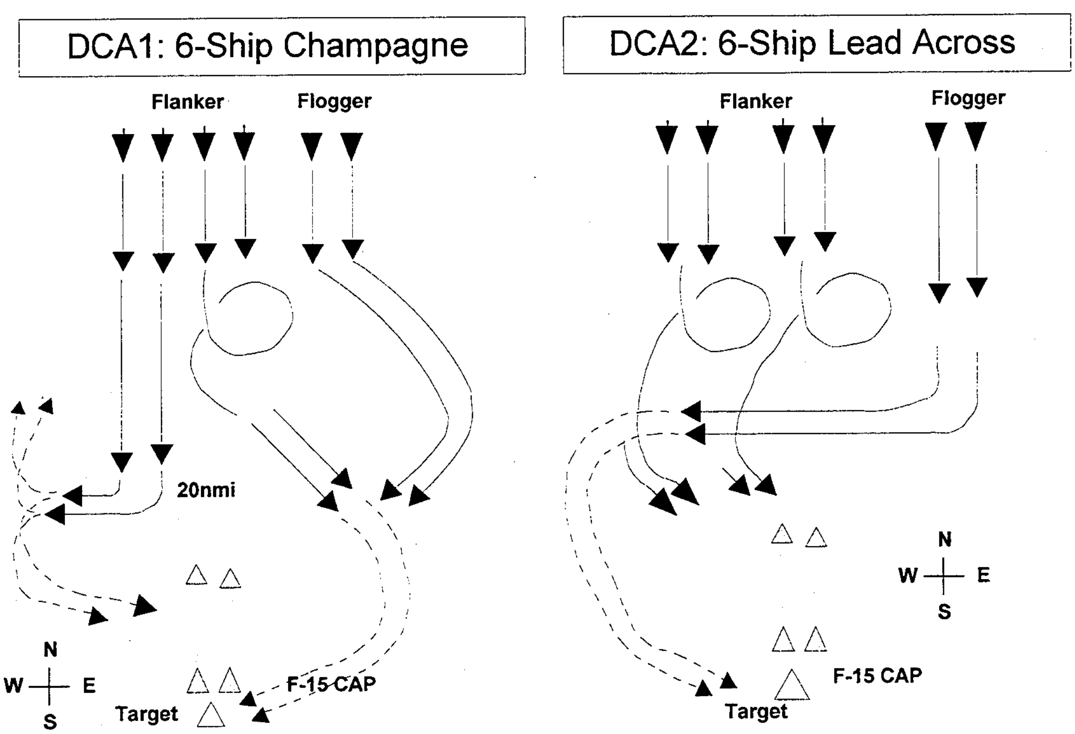

Figure 9. Two Variations of the Defensive Counterair (DCA) Missions Used in the Training Requirements Utility Evaluation (TRUE).

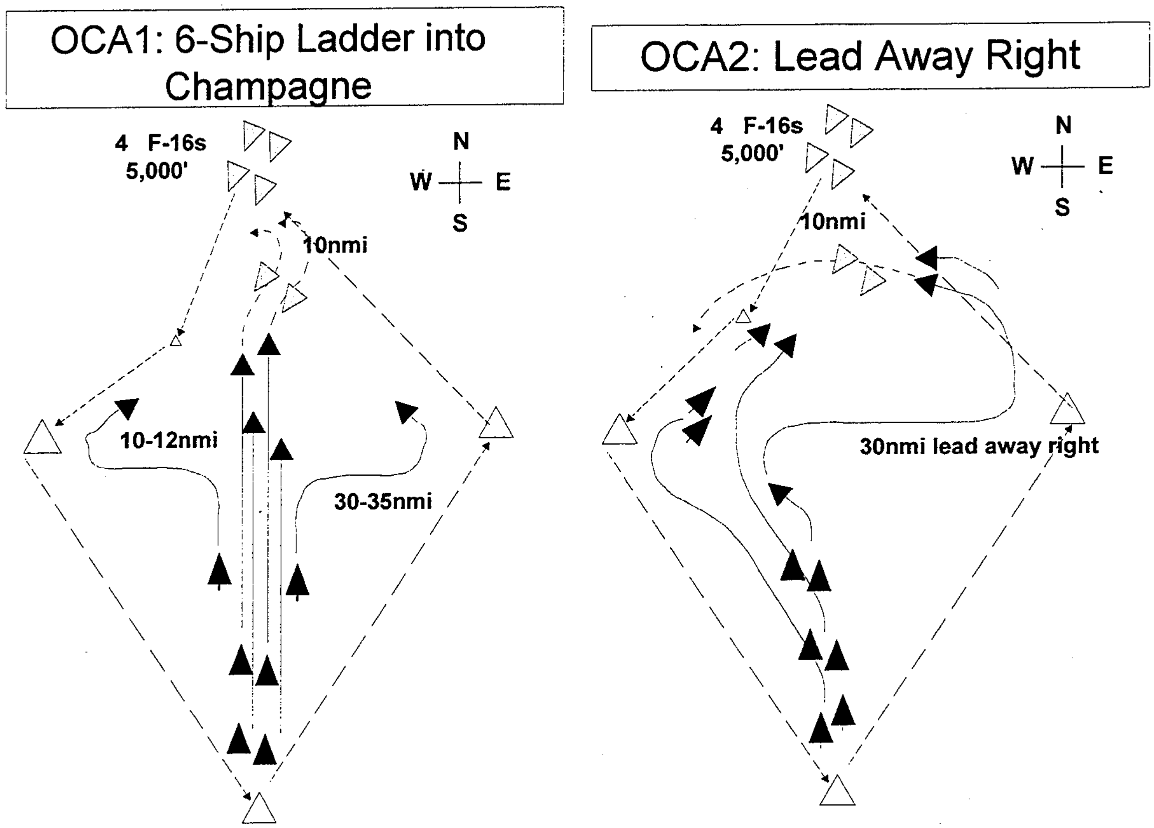

Figure 10. Two Variations of the Offensive Counterair (OCA) Missions Used in the Training Requirements Utility Evaluation (TRUE).

At the beginning of each week, pilots and controllers were briefed about the TRUE objectives and procedures. Participants then filled out a questionnaire listing 30 air combat mission tasks and skills and were asked to rate the desirability of receiving additional training on each. After a familiarization flight, teams flew three DCA and three OCA simulator sessions with three or four setups per session. Before each session, teams planned their missions including call sign assignment, lookout responsibilities, and plans for attack, mutual support, and re-attack. Each engagement was videotaped from the exercise control console using three, computer-controlled recorders. Each F-15 cockpit's front panel including the radar, radar warning, and armament control displays was recorded along with the overhead view of the engagement from the control console plus all audio communications and warnings. At the end of the simulator session, teams took the tapes to an independent debriefing room which contained facilities for synchronized playback of the tapes. After debrief, each team's lead pilot completed a questionnaire describing any difficulties they experienced during the missions and lessons learned for the next simulator session. Participant comments and critiques were also solicited during daily meetings with all pilots and controllers. During some TRUE weeks, pilots flew one-vs-one engagements between the two F-15 cockpits. After all simulator sessions had been completed, participants filled out a final questionnaire. On this questionnaire, participants rated the quality of training received in their current unit training program and from Multirad for each of 30 tasks and skills.

TRUE Participants

Twenty-three, USAF, F-15 pilots and 13 air weapons controllers participated in TRUE exercises. Pilot experience levels ranged from 300 to 2,500 total flying hours with a median of 1,400 total hours and

675 F-15 hours. The distributions of controller experience and flight hours of TRUE pilots by unit qualification are shown on Figures 11 and 12.

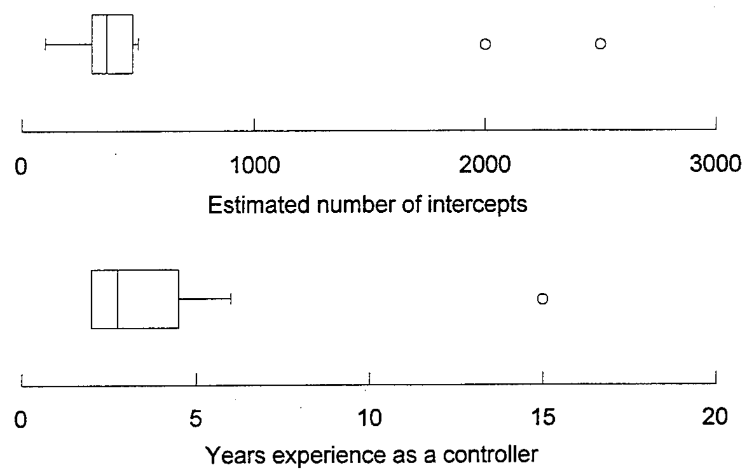

Figure 11. Distribution of TRUE Air Weapons Controller Experience.

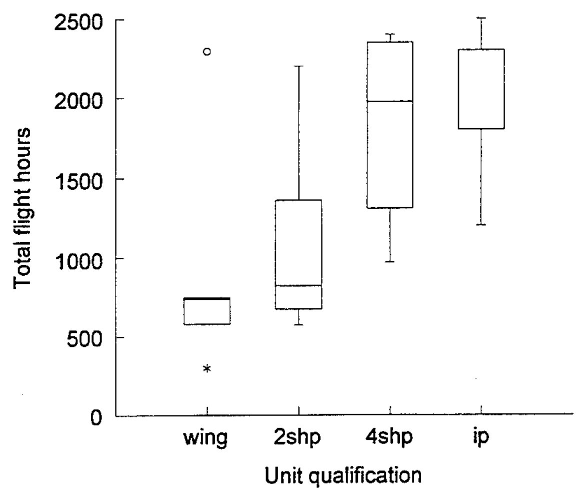

Figure 12. Distribution of TRUE Pilot Experience by Unit Qualification.

Results

During the four weeks of the TRUE, 78 h of multiship simulator exercises were scheduled and 72 were completed; 6 h (8%) were lost to major systems failures. Within the 72 h, 267 multiship setups were conducted. Of these, 204 setups were completed successfully while 63 (24%) required a restart due to minor system failure. The proportion of setups which experienced minor failures dropped from 30% during the first week to 21% during the other three weeks.

Network Analysis

Network traffic was captured for the final week of the TRUE to determine network loading and characteristics. Table 4 summarizes the data captured for the three engagement types used in the TRUE: basic fighter maneuvers (BFM), defensive counter-air (DCA), and offensive counter-air (OCA). The BFM engagements were one-on-one fights between the two MDRCs. The average utilization for all

engagements was less than one percent of network capacity while the maximum utilization was never more than 3.4%. Additionally, the network exceeded 90% of the maximum values only two to three times per engagement. Network analysis showed no collisions, no cyclic redundancy check errors, and no alignment errors. This was probably due to the fact the network was not heavily loaded.

Table 4. Multirad Network Utilization (Kbits/s).

	BFM	DCA	OCA
Min	42	45	56
Max	204	294	87
Avg	50	73	87

Table 5. Average Network Packet Utilization (Pkts/s).

	BFM	DCA	OCA
Vehicle Appearance	30	38	47
Radar	1	4	4
Emitter	0	16	16
Voice	5	16	16

The largest number of PDUs on the network was the vehicle appearance PDU followed by the voice, radar, and emitter PDUs (see Table 5). The deactivate, fire, and impact PDUs are all event-type PDUs and each took less than one packet per second during the TRUE. The network loading is consistent for the three different scenarios. The number of entities on the network is dependent on pilot input. The more ECM and missiles are deployed, the more entities are placed on the network. The average number of entities for each type engagement was 24 entities for each BFM, 38 entities for each DCA, and 39 entities for each OCA. RVA algorithms reduced network traffic by 65% to 85% over the course of the TRUE. Because tactics and maneuvers are different for each engagement, the effectiveness of RVA on network loading was also different for each engagement.

Although network performance was near perfect, a hardware discrepancy in some of the NIU's ethernet boards was discovered early in the program that affected network reliability. The discrepancy was a result of the fact that the only contacts between the circuit board and the connector were solder joints on the pins. After repeated use of the connectors, the solder joints would fail, resulting in loss of data. This loss of data caused unpredictable operations on the network and large amounts of jitter. Once the connectors were repaired by the manufacturer, the problem was resolved.

Component Utility

F-15 Cockpits - The MDRC cockpits used by the TRUE pilots were rated as wholly acceptable for air combat training. The glass cockpit and touch panel were downrated only in that the displays were not positioned exactly as in the aircraft, and pilots had to scan for a moment to find what they were looking for. The lack of rudder pedals was cited as a problem only in close combat which was not a Multirad objective. A major difficulty, however, was that some of the avionics software in the simulator was not current with the aircraft. Pilots complained vigorously that the older software prevented them from using their weapons systems as they would in the aircraft. This lack of currency affected the pilots' tactics and greatly reduced the value of Multirad training.

Visual Display Systems - The offensive and defensive counterair missions were designed to emphasize beyond-visual-range, air-to-air combat tasks: e. g., radar searching, sorting, targeting, weapons employment, communication, tactics, and mutual support. However, pilots uniformly reported that they experienced significant difficulties in completing their missions due to problems with the visual displays. Both the dome and the DART received high praise for depicting the terrain and horizon. This information was used for judging attitude or for low altitude flight when necessary. Difficulties were primarily experienced in seeing other aircraft. An instaneous field of regard of less than 180 deg prevented pilots from maintaining tactical formation as they normally do in the aircraft, i. e., at 3 or 9 o'clock. The AOI in the dome received particular criticism. A pilot in the dome could not see his wingman in tactical formation using either peripheral vision or a quick saccade left or right. The pilot in the dome

had to turn his head 90 deg and spend a second or two looking for his wingman. DART pilots experienced less difficulty in maintaining tactical formation within 1 nmi. Problems with field of view also prevented pilots from providing mutual support while engaged with enemy aircraft.

Pilots described their ability to resolve an air target as acuity which is a function of display brightness, contrast, and resolution, plus the level of detail in the computer-generated aircraft model. Level of detail varied with range from the eyepoint. The major problem caused by lack of acuity was inability to determine the aspect of other aircraft. Pilots could not determine in which direction other aircraft were heading without watching their target's flight path for several seconds. Pilots also reported that they could not maintain tactical formation beyond 0.5-1 nmi without using many radio calls due to inability to judge aspect. In addition, pilots could not visually determine distance from other aircraft at low levels of detail. Acuity problems also plagued pilots at the merge where the F-15 passes an enemy aircraft at high speed. When a pilot could visually locate the threat aircraft or his wingman he could not tell which way the other aircraft were going quickly enough to take a tactical advantage. Overall, both DART and dome pilots reported that visual flying was difficult and that they learned to use nighttime tactics and detached mutual support.

To increase the range at which aircraft could be detected and identified, a simulator-unique effect (i. e., a simism) was introduced. At maximum visual detection range, an air target was represented as a white point light. At maximum identification range, enemy aircraft were represented as red point lights while friendlies were represented as blue, flashing lights. This simism greatly increased pilot acceptance; however, pilots continued to complain that they could not determine another aircraft's range or aspect until it was within 0.5-1 nmi.

At the end of each week, pilots were asked to rate the value of the training received using the Multirad system for each of 30 flight tasks. Multirad training was rated highest for nonvisual tasks, notably, operation against multiple enemy aircraft and practice working with an air weapons controller. Among the visual tasks, Multirad training was rated highest for dissimilar air combat training and defense against SAMs. Mean ratings for the DART and Dome are shown on Figure 13. The tasks are coded:

DACT	Dissimilar air combat training
SAM DEFENSE	Defense against surface-to-air missiles
TWO SHIP TAC	Two-ship tactics
VISUAL LOW	Visual, low altitude flight
VISUAL LOOK	Visual lookout
MUTUAL SUPT	Mutual support
LOW ALT TAC	Low altiude tactics
VISUAL ID	Visual identification of target aircraft
TACTICAL FRM	Tactical formation.

Differences in ratings between the two displays are not significantly different.

Twelve pilots participated in DART vs dome BFM exercises. Aircraft were initialized facing each other 10 nmi apart. Pilots were instructed to fly towards each other and turn to engage as they passed. After three setups, pilots traded cockpits and flew three more. Overall, 36 out of 55 engagements (65%) were won by the pilot flying in the DART.

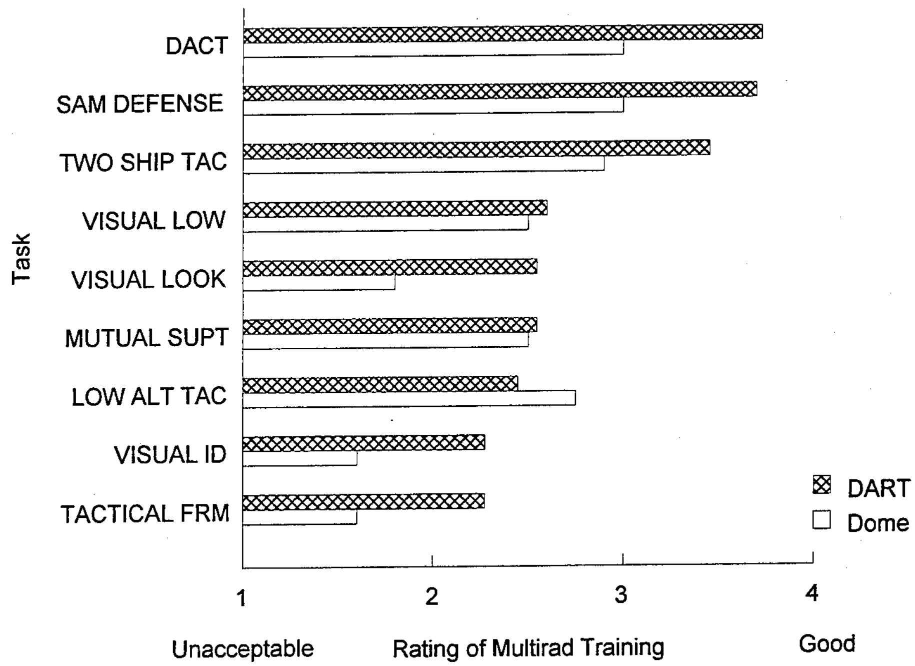

Figure 13. Comparison of Mean Ratings for Multirad Training for the DART and Dome Visual Displays on Visually Demanding Tasks.

Opposing Forces - Houck et al. (1991) found in the Advanced Air Combat Training program that the most significant training benefits came from the opportunity to engage multiple bogeys. However, in the first week of the TRUE, participants found so many flaws in the representation of opposing aircraft that they rated the training to have little or no value. TRUE pilots stated that both the manned and computer-generated threat pilots had perfect situation awareness, flew aircraft that were too fast, had 360deg radars which could not be defeated, and fired invincible missiles. Many of these problems were found to originate from aircraft and radar models used in the ATES which were generated from unclassified and widely available reference sources. While each parameter used in these models may have been only slightly optimistic, combining them all into a set of threat models produced an unbeatable foe. Adjusting the threat model parameters using better data or pilot acceptance greatly increased Multirad training effectiveness ratings during the remainder of the TRUE.

One difficulty which could not be corrected was the infrared guided missile model used by the manned opposing forces pilots flying CETs. This model was originally developed for intercept training against a nonresponding target. If the CET pilot has correctly positioned his aircraft with respect to the target, the missile scores a kill. When integrated into Multirad, however, the target aircraft's pilot would attempt to defeat the missile by effecting countermeasures. These countermeasures had no effect on the CET's missile. Pilots greatly objected to this aspect of Multirad simulation since it prevented them from practicing their skills at missile defense. The only corrective measure possible during the TRUE evaluation was to brief the CET pilots to hold their shots until the probability of a kill was very high. This solution satisfied no one.

Air Weapons Controller Station - Although the SCCENTS station provides only a functional representation of an AWACS or GCI display rather than a high fidelity physical simulation, the controllers who participated in the TRUE gave uniformly high ratings to the training provided by Multirad. During interviews, controllers stated that the SCCENTS station did present a number of simisms to which they quickly adapted. The most significant simism was that the simulated radar was too good. Aircraft

altitudes were identified too precisely and there were no blind areas behind terrain features. The training value in Multirad came from the opportunity to practice several setups within a simulator period and then to debrief these engagements with the pilots while watching the videotapes and listening to their radio calls.

Debriefing Station - Pilots and controllers rated the computer system for controlling the synchronized videotapes as being overly complex. Only a few participants actually learned to use the system to its full advantage. Redesigning the system to make it fighter pilot-friendly is a high priority item for improving Multirad. Aside from the complexity, however, pilots agreed with the controllers that reviewing videotapes of the engagement added greatly to the value of Multirad training. In particular, seeing the overhead view together with their own radar allowed pilots to evaluate the effectiveness of their actions in context of the entire mission.

Interest in Additional Training

Pilots rated their interest in receiving additional training on each of 30 tasks using a scale from 1 = additional training is not desirable to 5 = additional training is extremely desirable. Mean ratings are presented in Figure 14. The 30 tasks on the figure are coded:

TACTICAL FRM	Tactical formation
VISUAL LOW	Visual low level flight
SEPARATION	Separation tactics
VISUAL ID	Visual identification of target aircraft
LOW ALT TAC	Low altitude tactics
DEBRIEFING	Mission debriefing
EGRESS TAC	Egress tactics
INTRAFLT COM	Intraflight communication
TWO-SHIP TAC	Two-ship tactics
COM JAMMING	Communication jamming
TEWS	Tactical Electronic Warfare System assessment
INTERCEPT	Tactical intercept
MISSILE	Missile employment
ECM	Employ ECM/ECCM
AI RESPONSE	Reaction to airborne interceptors
MUTUAL SUPT	Mutual support
WEATHER	All-weather employment
CHAFF	Employ chaff/flares
VISUAL LOOK	Visual lookout
EID	Electronic identification of target aircraft
TACTICS/PLAN	Tactics/mission planning and briefing
ESCORT TACTICS	Escort tactics
RADAR LOOK	Radar lookout
WORK W/GCI	Work with AWACS/GCI
SAM DEFENSE	Reaction to surface-to-air missiles (SAMs)
RADAR SORT	Radar employment/sorting
BVR	Beyond-visual-range employment
ALL-ASPECT D	All-aspect defense
DACT	Dissimilar air combat training
FOUR+ BOGEYS	Multibogey, four or more

The five tasks with the lowest interest ratings are primarily visual tasks. The tasks with the highest rated interest in receiving additional training are tasks which can usually be practiced only in large exercises or cannot be practiced except in simulation, e.g. defense against SAMs. This result is in agreement with

Houck et al. (1991) who found that pilots were most interested in receiving additional training for tasks which are least frequently practiced in the aircraft. Interest is low for tasks such as tactical formation or separation tactics which are practiced on all air-to-air sorties.

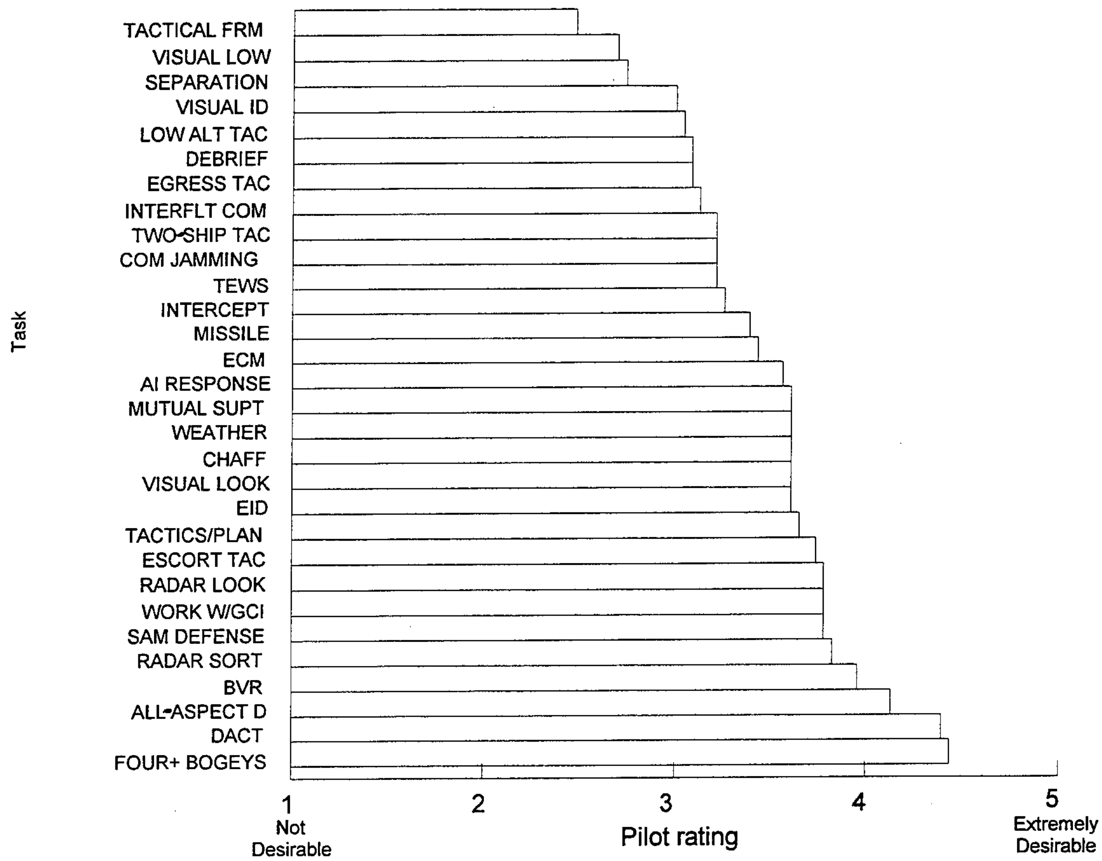

Figure 14. Pilot Ratings of Interest in Receiving Additional Training for 30 Mission Activities.

Value of Multirad and Current Unit Training

Using the scale of 1 = unacceptable to 5 = excellent, pilots rated the value of their current unit training and Multirad training for each of the 30 tasks. The lowest and highest rated tasks for unit and Multirad training are listed in Table 6. While some tasks, notably radar lookout, were rated highly for both Multirad and current unit training, more tasks were given high ratings for one training environment and low ratings for the other. For example, visual lookout and tactical formation were the lowest rated tasks for Multirad but among the highest rated tasks for current unit training. Likewise, work with GCI controllers and engagements against four or more bogeys were among the lowest rated tasks for current unit training and among the highest rated tasks for Multirad.

The differences between the mean ratings for unit and Multirad training are plotted on Figure 15. Tasks which were rated much higher in the current unit than in Multirad are primarily visual. These tasks were also among the lowest rated tasks for interest in receiving additional training. Tasks which were rated higher in Multirad than in the current unit are tasks which are not frequently practiced outside of large-scale exercises. Also, tasks rated higher for Multirad training were among the highest rated tasks for interest in receiving additional training. This finding is also in agreement with Houck et al. (1991) who reported that pilots rated multiplayer, simulator-based training higher than unit training for tasks which cannot be practiced in aircraft due to safety, cost, and security restrictions.

Table 6. Lowest and Highest Rated Tasks for Current Unit and Multirad Training.

	Current Unit	Multirad
Lowest rated tasks	SAM defense	Visual ID
	Com jamming	Tactical formation
	ECM/ECCM	Com jamming
	Work w/GCI	Visual lookout
	Four+ bogeys	Visual low altitude
Highest rated tasks	Visual lookout	Radar lookout
	Tactics/planning	Work w/GCI
	Mutual support	Radar sorting
	Tactical formation	BVR employment
	Radar lookout	Four+ bogeys

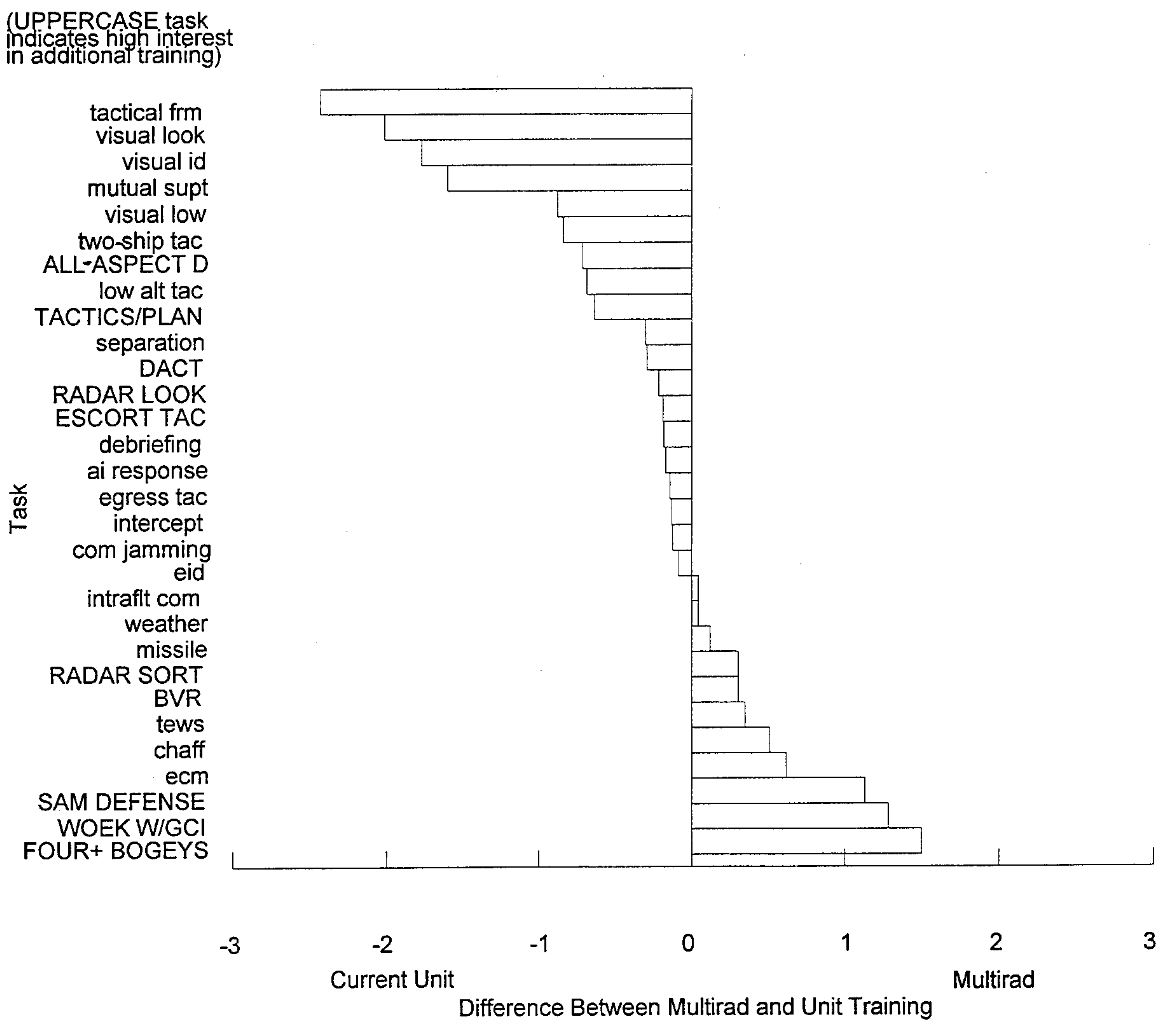

Figure 15. Differences Between Pilot Ratings of Training Effectiveness for Multirad and Current Unit Training for 30 Mission Activities.

Similar ratings of current unit and Multirad training were collected from air weapons controllers for the subset of ten tasks which were applicable. The differences between the mean ratings for unit and Multirad training are plotted on Figure 16. For all tasks, Multirad training was rated higher than current unit training with highest ratings for those rarely practiced; i. e., dissimiliar air combat tactics, debriefing with the pilots, and engagements against multiple bogeys.

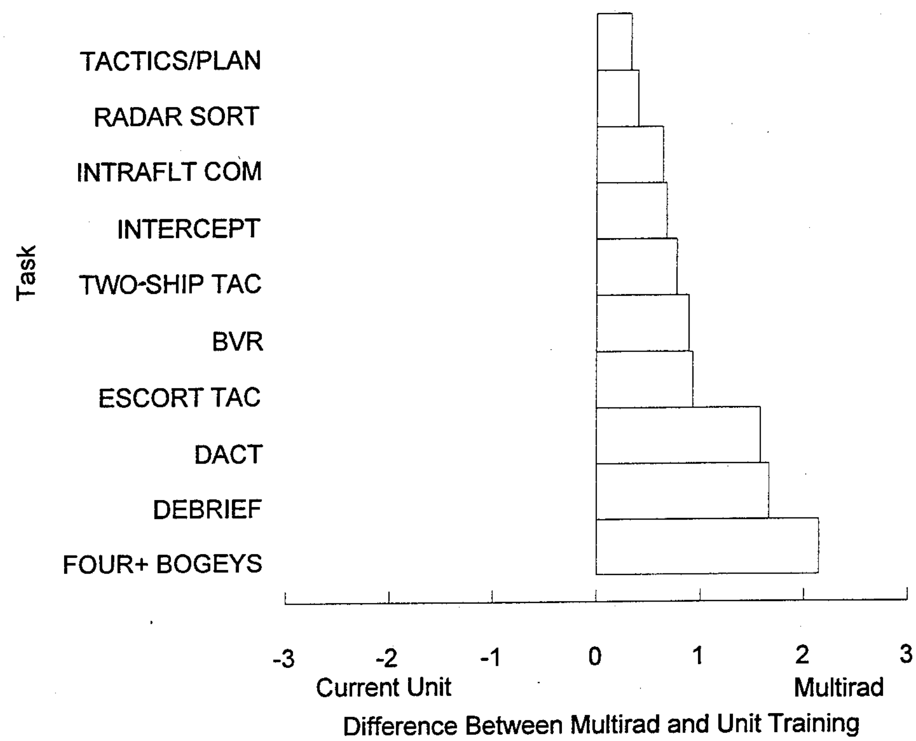

Figure 16. Differences Between Air Weapons Controller Ratings of Training Effectiveness for Multirad and Current Unit training for 10 Mission Activities.

Mission Performance

During the TRUE, each team typically flew three OCA simulator sessions and three DCA simulator sessions with three or four setups per session. Mission performance for each OCA and DCA session was summarized as average number of enemy aircraft shot down (kills) per setup and average number of F-15s shot down (morts) per setup. These data were compared for less experienced pilots (wingman or two-ship flight lead, 787 median flight hours) and more experienced pilots (four-ship flight leads and instructor pilots, 1975 median flight hours). The data are summarized on Figure 17 (DCA) and Figure 18 (OCA).

DISCUSSION

Lessons Learned

The objective of the TRUE was to determine whether the benefits observed in the training utility studies at MCAIR could be replicated with a lower cost, distributed interactive simulation. Overall, the TRUE demonstrated that multiship air combat simulation can be successfully conducted using a SIMNET-compatible approach. The lessons learned from TRUE provide guidance for the development of future systems and further modifications to the Multirad system.

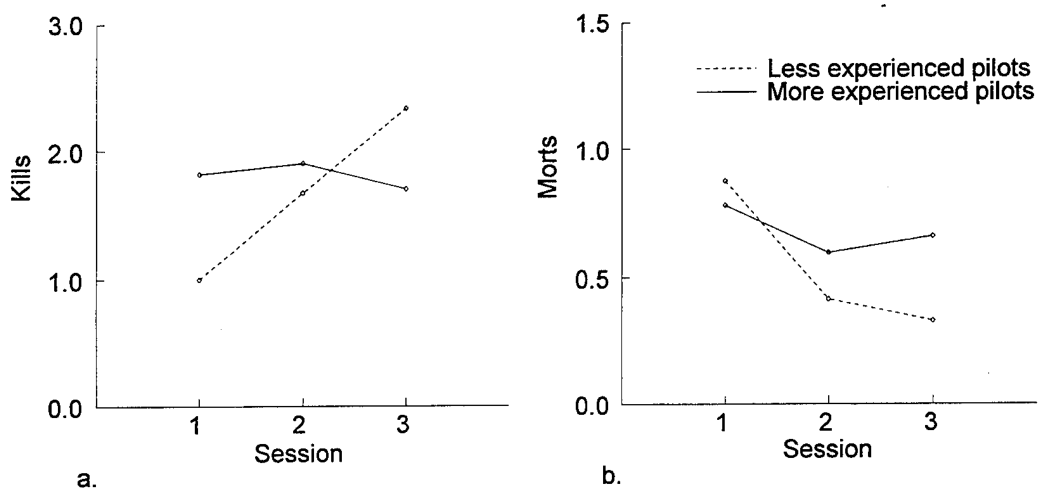

Figure 17. Mission Performance for the TRUE DCA Scenarios: (a) average enemy kills per session, and (b) average F-15 losses (morts) per session for less and more experienced pilots.

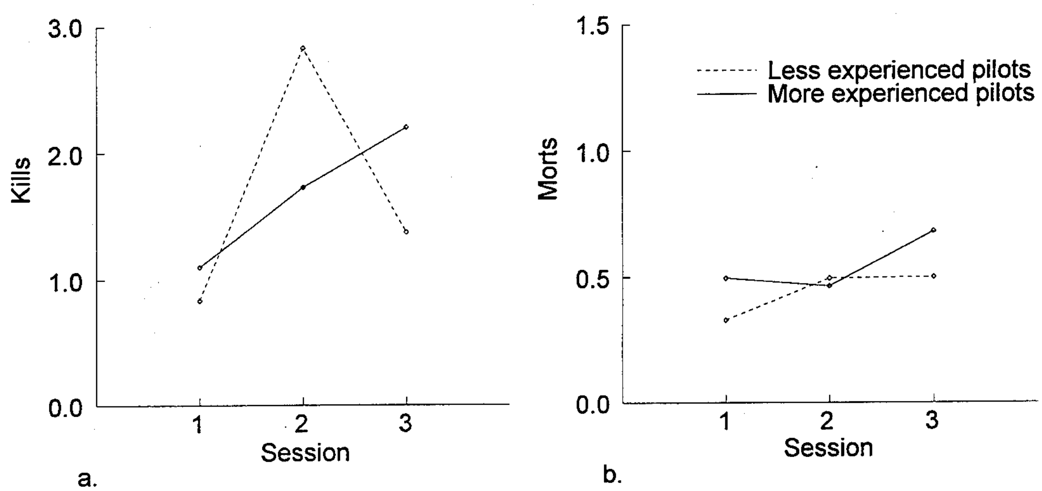

Figure 18. Mission Performance for the TRUE OCA Scenarios: (a) average enemy kills per session, and (b) average F-15 losses (morts) per session for less and more experienced pilots.

Functional vs Physical Fidelity

Boyle and Edwards (1992) point out that, "A real program killer is unmet pilot expectations. If you are not simulating it, don't try to make it look like you are," (p. 496). This lesson was repeated during the TRUE in that functions which were incompletely modeled but were central to the missions being practiced raised the most serious objections. Notably, the lack of currency between the pilot's aircraft and the simulated F-15 software raised howls of protest. Pilots were compelled by the simulation to practice using tactics that they would not use if they were to go to war tomorrow. In this case, reduced fidelity was not good enough. Compare this response to the glass cockpit MDRC. The front panel was a CRT, there were no rudder pedals, and most switches were missing. None of these faults affected the mission and they caused no objections. Systems which were critical to the mission, hands-on-throttle-and-stick (HOTAS) controls and the displays used in air combat, were high fidelity simulations. The net effect was a fully acceptable trainer, except for the software. Air weapons controllers using the SCCENTS station had a similar experience. The physical similarity between the SCCENTS and an actual AWACS or GCI station

was limited to the mission critical information on the display. Controllers adapted to the simisms caused by the noncritical elements of the SCCENTS and rated the system as providing high value training.

Integration of existing systems

The CET used as a manned opponent in the TRUE is a part task trainer designed to teach the shooter to intercept an air target and to put his aircraft into an optimal firing position. The objective of this part-task trainer is to teach the pilot to make the intercept and to take a good shot. The missile model provides feedback to the pilot about his intercept: a good shot gets a kill and a bad shot misses. This missile model completely fulfills the CET's training objectives. The objectives of Multirad training, however, include training the F-15 pilot to defend against air-to-air missiles. The infrared (IR) missile models used by the ATES were sensitive to flares and the target aircraft's throttle setting so that the F-15 pilot could, if he was quick enough, defeat an ATES missile. CET missiles were not designed to provide defensive training for the target aircraft's pilot and were therefore not responsive to flares or other countermeasures. The CET's missile is not a low fidelity model within its intended application. Integrated into Multirad, however, the CET missile was unacceptable. Integrating existing systems requires very careful consideration of each system's original objectives and how that system operates. Networking existing systems will support effective training only if the objectives of the integrated system are clearly stated and the capabilities of the individual components are evaluated in terms of these objectives.

Multirad Network Limitations

The simulation network was not a limiting factor on the current Multirad system. Network utilization for the TRUE effort never exceeded 3.4% of the full capacity of ethernet. With bandwidths of 100 Megabits/s available for FDDI, the network should continue to fulfill the requirements of mission rehearsal and team training. The limiting factors found during the TRUE were: host to NIU interface, NIU processing capability, and host computer processing capability. The MDRC ICDs were developed to maximize the amount of valuable information passed to and from the network. As the number of entities on the network increases, the simulator and NIU spend more time transferring and processing this data. Data minimization methods must be developed to optimize not only the data that is sent to and from the host but also the frequency of these transfers. Also, the network analysis showed the NIU spent the largest amount of time building up the host data buffer. For example, it took an average 49.5% (24.75 ms) of the total frame for the NIU to build the MDRC's data buffers. The primary restriction encountered in setting up the TRUE scenarios, however, was the physical limitations of the host simulators' computing power.

Test Procedures and Configuration Control

As the integration process progressed, it became apparent that more testing and configuration control were needed. The time between the TRUE scenarios was not always adequate to thoroughly test changes to the overall system. Additionally, the integration effort was accomplished by four separate contractors and the government. Some problems occurred due to miscommunications between the integration teams while others were a result of misinterpretations of the protocols and ICDs. Still others were due to poor configuration control of software. Problems encountered and fixed would sometimes reappear in scenarios. Thorough test procedures and rigorous configuration control are crucial for an integration effort of this type.

Visual Displays

A major limitation on the value of Multirad training resulted from the visual displays. While wide field-of-view displays were rated by pilots as necessary for effective training, inadequacies in the visual display systems reduced pilot situation awareness and induced simulator-unique behaviors. Pilots could not maintain tactical formation or count on mutual visual support. Although the DART had poorer

resolution than the dome, pilots preferred the DART due to its greater contrast and larger instantaneous field of view. While their mission performance was often successful, pilots asserted that their tactics were sometimes different from aircraft tactics leading to opportunities for negative transfer of training. Representative comments from TRUE pilots include, "We need two DARTs so we can keep sight of each other. With current systems we are developing simisms," or, "He who sees will have better SA [situation awareness]," and, the most telling comment was, "I would have died less if I could have seen more."

Multiship Training

TRUE was conducted as an engineering test of the Multirad system. However, TRUE also provided the opportunity to gather behavioral data on training interests and the potential applications of mutiship, simulator-based training for air combat. Overall, the results of TRUE are in agreement with the findings of Houck et al. (1991). Although the engineering development simulator system used by Houck et al. at MCAIR had more capability than the present Multirad system, TRUE pilots rated simulator training higher than current unit training for a similar list of tasks. These include tasks which can be performed single-ship but are infrequently practiced such as radar sorting against multiple targets. The high rated tasks also include skills which can only be practiced within the context of a team. These tasks include work with a GCI controller and operations against four or more bogeys.

Dion and Bardeen (1990) predict that the major benefit of multiplayer combat training will be the development of team skills. These benefits will come from, "training situations in which the team learns to develop adaptive teamwork skills required in real time for uncertain problems, and an expanded repertoire of team experiences," (p. 468). It is unclear, however, whether the benefits of multiplayer simulation come from development of team skills or from the development of individual skills at tasks which can only be practiced within a team context. Crane (1992) predicts that training will be of most benefit for skills which pilots have had the least opportunity to practice. This prediction is based on cognitive models of expertise which assert that a journeyman lacks the expert's extensive knowledge base and is unable to quickly recognize the significant elements within a mission and to select an appropriate response. The idea that practice will be of most benefit for the least practiced skills is supported by two sources of evidence within TRUE.

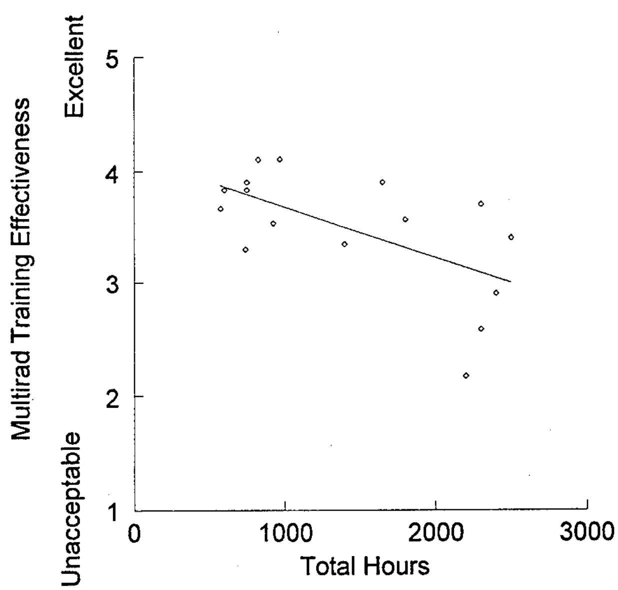

Figure 19. Mean Effectiveness Ratings Assigned to Multirad Training Compared to Total Flight Hours.

Pilot ratings of Multirad training value were averaged over the 30 tasks listed on Figure 15 and compared to overall experience. There is a significant, negative correlation between flight hours and average rating of Multirad training effectiveness ($r = -.62$), (see Fig. 19). Overall, the ratings of the more experienced pilots were lower and variable. Less experienced pilots gave consistently high ratings for Multirad training and gave significantly higher ratings than the more experienced pilots for tactics, mission planning, and mutual support. High experience pilots gave Multirad higher ratings than the less experienced pilots only for chaff employment. During interviews, wing pilots and less experienced two-ship flight leads stated that if given the opportunity, they would use the Multirad system "everyday." On the other hand, instructor pilots and four-ship flight leaders stated that they found the Multirad system interesting but that the training was not particularly valuable. However, these pilots also stated that they would be very interested in using a system with 4 F-15s and 8 - 12 threat aircraft.

Pilot performance data from the TRUE, although limited, also tends to support the idea that Multirad training is most valuable for infrequently practiced tasks. In the TRUE training scenarios, the DCA mission was less complex and more familiar than the OCA scenarios. As can be seen in Figure 17, the more experienced pilots showed relatively high levels of performance, both kills and morts, and did not improve over the three opportunities to practice this mission. The less experienced pilots, however, initially performed more poorly than the more experienced pilots but improved over the week in both kills and morts. For the more complex and less familiar OCA scenarios, the more experienced pilots showed improvements in kills (Figure 18). The less experienced pilots did not improve their kill performance and neither group improved on morts. This suggests that the mission scenario was overly complex and that a building block approach should have been employed. Since the mission activities in TRUE which were highly rated for Multirad training are both team tasks and infrequently practiced, no conclusion can be drawn regarding Dion and Bardeen's (1990) prediction that the benefit of multiplayer simulation will be development of team skills.

Conclusions

There is a growing realization that combat mission training cannot be fully accomplished using in-flight training. The evaluations conducted at MCAIR and AL/HRA demonstrated the experienced pilots and air weapons controllers perceive multiship air combat simulations as providing additional air combat training opportunities beyond current unit training. Multiship simulation provides pilots and controllers the means to practice tasks which cannot be practiced in the aircraft due to cost and peacetime training restrictions.

Multiship air combat simulations using a super-minicomputer, shared memory architecture were successfully transitioned to a distributed microprocessor architecture using a communications system which is compatible with other military trainers. While this transition has provided high-level training using low-cost devices, several limitations remain. Most notably, the out-the-window visual simulation cannot provide the level of resolution necessary to judge aspect and closure of air targets at realistic ranges. Also, the opportunity to integrate existing training devices into a multiplayer network may create new difficulties. Each device's capabilities and level of fidelity needs to be carefully considered with respect to the training objectives of the integrated system. Ill-considered choices may degrade rather than enhance the quality of training.

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